

Observations of Hydration and Dehydration **in the Winter 2000 Arctic Stratosphere**

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Introduction

The 1999-2000 winter was characterized by unusually cold conditions in the Arctic lower stratosphere, including a larger area exposed to temperatures cold enough to nucleate nitric acid trihydrate (NAT) than ever measured before in the Arctic [e.g., Manney and Sabutis, 2000]. If the polar vortex gets colder over the next several decades, this winter may typify Arctic winters of the future. Solid PSCs that form below 195 K are ubiquitous in the Arctic winter stratosphere [Fahey et al., 2001] and are predominantly NAT [Voigt et al., 2000]. Ice PSCs are stable below the frost point (~ 188 K), so Arctic dehydration has been observed mainly in the coldest winters. That raises the question: did the widespread presence of polar stratospheric clouds (PSCs) in 1999-2000 cause irreversible removal or redistribution of stratospheric water?

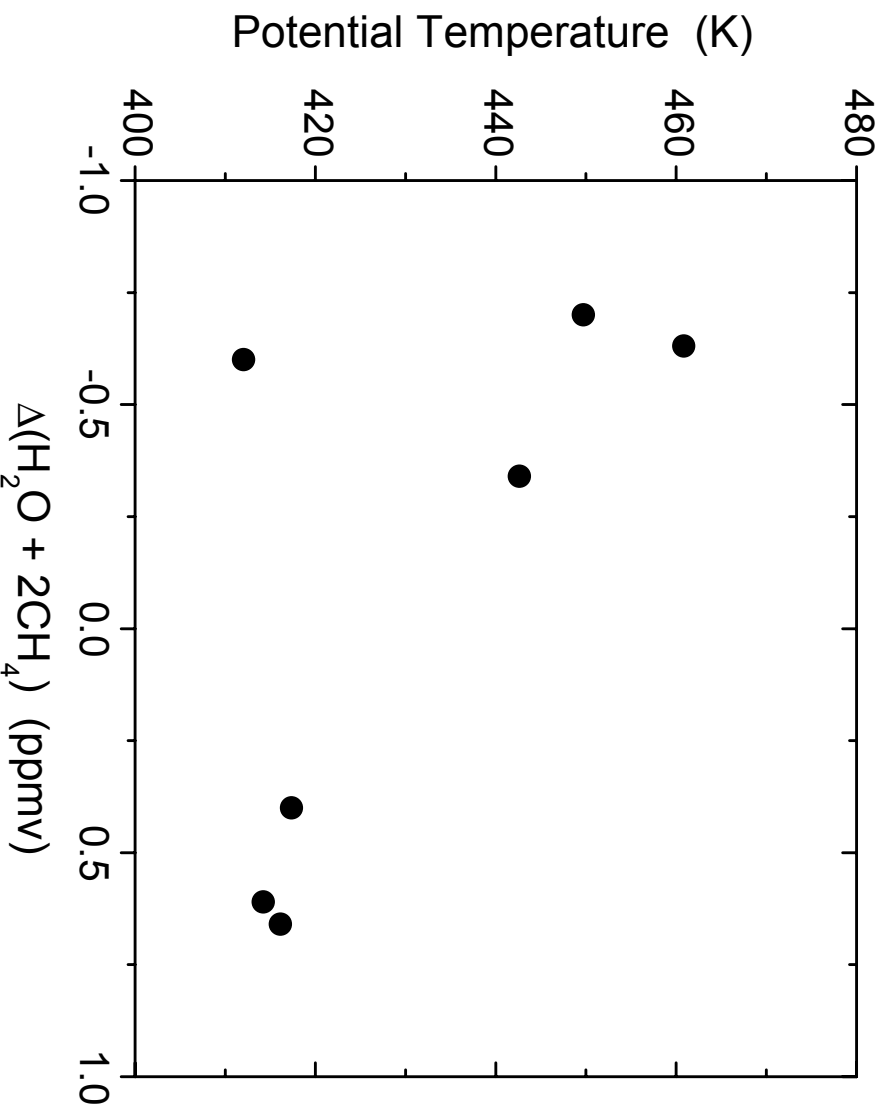
We examine here total hydrogen $\mathbf{H} = \text{H}_2\text{O} + 2\text{CH}_4 + \text{H}_2$ from the NASA ER-2 high-altitude aircraft during the SAGE III Ozone Loss and Validation Experiment (SOLVE). The partitioning of hydrogen between these species is changed by photochemical oxidation of CH_4 into H_2O and H_2 , oxidation of H_2 into H_2O , and HO_x chemistry that includes both sources and sinks of H_2 [e.g., Le Texier et al., 1988; Dessler et al., 1994; Hurst et al., 1999]. Since these are the three dominant hydrogen-bearing species in the stratosphere, \mathbf{H} should be conserved in air in which the seasonal cycle of water has been averaged out. In this case, \mathbf{H} is changed only by long-term trends in CH_4 or H_2O , dehydration, or hydration.

Total Hydrogen Budget

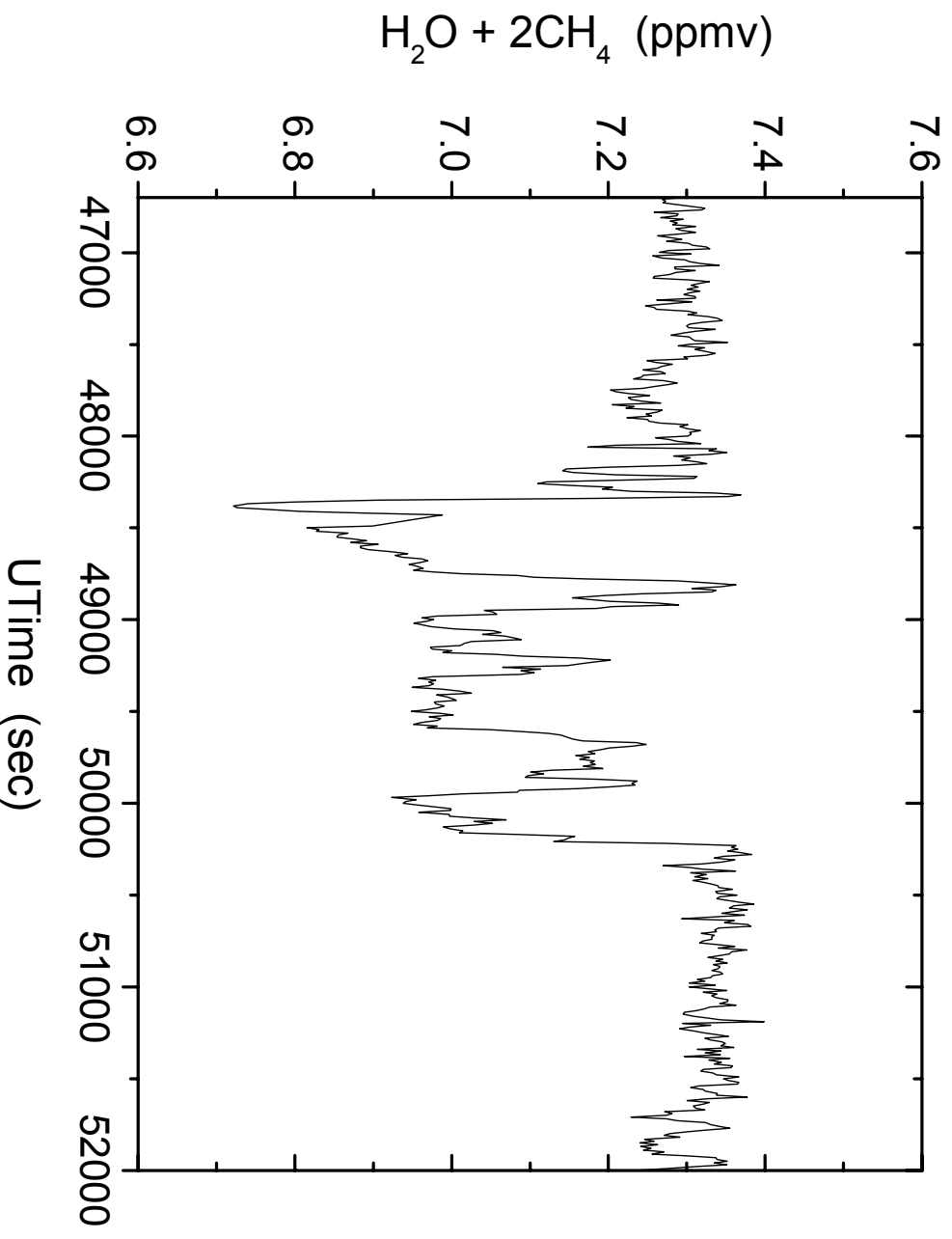
	H ₂ O + 2CH ₄		H ₂ O + 2CH ₄ + H ₂	
	JLH	Harvard	JLH	Harvard
Extravortex (E)	7.32±0.13	7.07±0.18	7.98±0.07	7.75±0.15
Mean Vortex (V)	7.38±0.11	7.11±0.15	N/A	N/A
Vortex, deploy 1	7.41±0.11	7.09±0.11	N/A	N/A
Vortex, deploy 2	7.36±0.11	7.13±0.11	7.89±0.12	7.66±0.15
Difference, E-V	-0.06±0.17	-0.04±0.23	0.09±0.14	0.09±0.21

Was there a net loss of total hydrogen from the Arctic stratospheric polar vortex during the 1999-2000 winter? Shown above are mean stratospheric data filtered by CH₄ < 1.45 ppmv and $\theta > 400$ K to eliminate the seasonal cycle of water. The difference between mean extravortex and vortex values show insignificant changes in total hydrogen. Extravortex **H** is greater than vortex **H** solely due to low H₂ in the Arctic vortex. The largest difference between the measurements is due to a bias between the JPL Laser Hygrometer (JLH) [May, 1998] and the Harvard Lyman- α Hygrometer [Weinstock et al., 1994]. CH₄ data are from the Aircraft Laser Infrared Absorption Spectrometer (ALIAS) [Webster et al., 1994], and H₂ data are from the Airborne Chromatograph for Atmospheric Trace Species (ACATS-IV) [Elkins et al., 1996]. SOLVE deployment #1 is Jan. 14 through Feb. 3, 2000, and deployment #2 is Feb. 26 through Mar. 16, 2000.

Dehydration / Rehydration Episodes

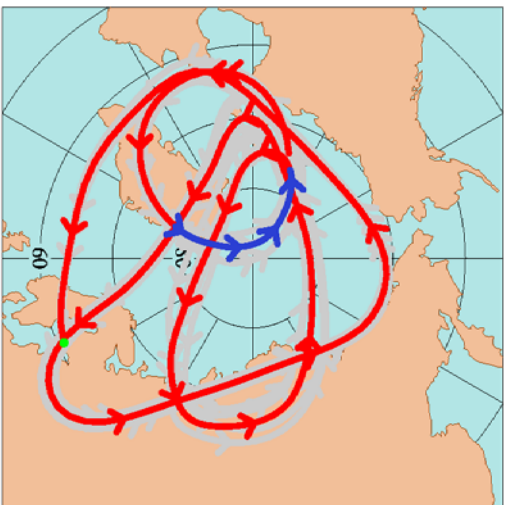


Shown above are the largest excursions from local background values of $\text{H}_2\text{O} + 2\text{CH}_4$ measured during SOLVE with JFH H_2O and ALIAS CH_4 . Above 430 K, $\Delta(\text{H}_2\text{O} + 2\text{CH}_4) < 0$ due to dehydration. Below 430 K, $\Delta(\text{H}_2\text{O} + 2\text{CH}_4) > 0$ due to hydration, with one notable exception of dehydration on March 7, 2000.



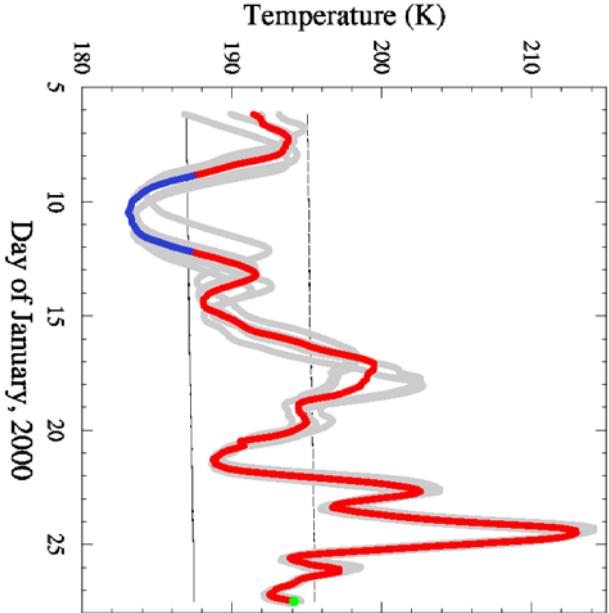
This figure shows the sum $\text{H}_2\text{O} + 2\text{CH}_4$ (JLH H_2O , ALIAS CH_4) during the ER-2 flight of Jan. 27, 2000. $\text{H}_2\text{O} + 2\text{CH}_4$ was low for more than 430 km along the ER-2 flight path, indicating up to 0.63 ppmv dehydration. Negligible H_2O was sequestered in the condensed phase during this flight segment. The dehydrated air parcels were located at potential temperatures ranging from 456 to 468 K, pressures from 47.5 to 55.1 hPa, and altitudes of 20.4 to 20.9 km.

Trajectories for Dehydration Event Cluster generated for Jan. 27, 2000, 48400 UT



- Measurement location
- Central trajectory
- Location of cold pool
- Other trajectories in cluster

Trajectories for Dehydration Event
Cluster generated for Jan. 27, 2000, 48400 UT

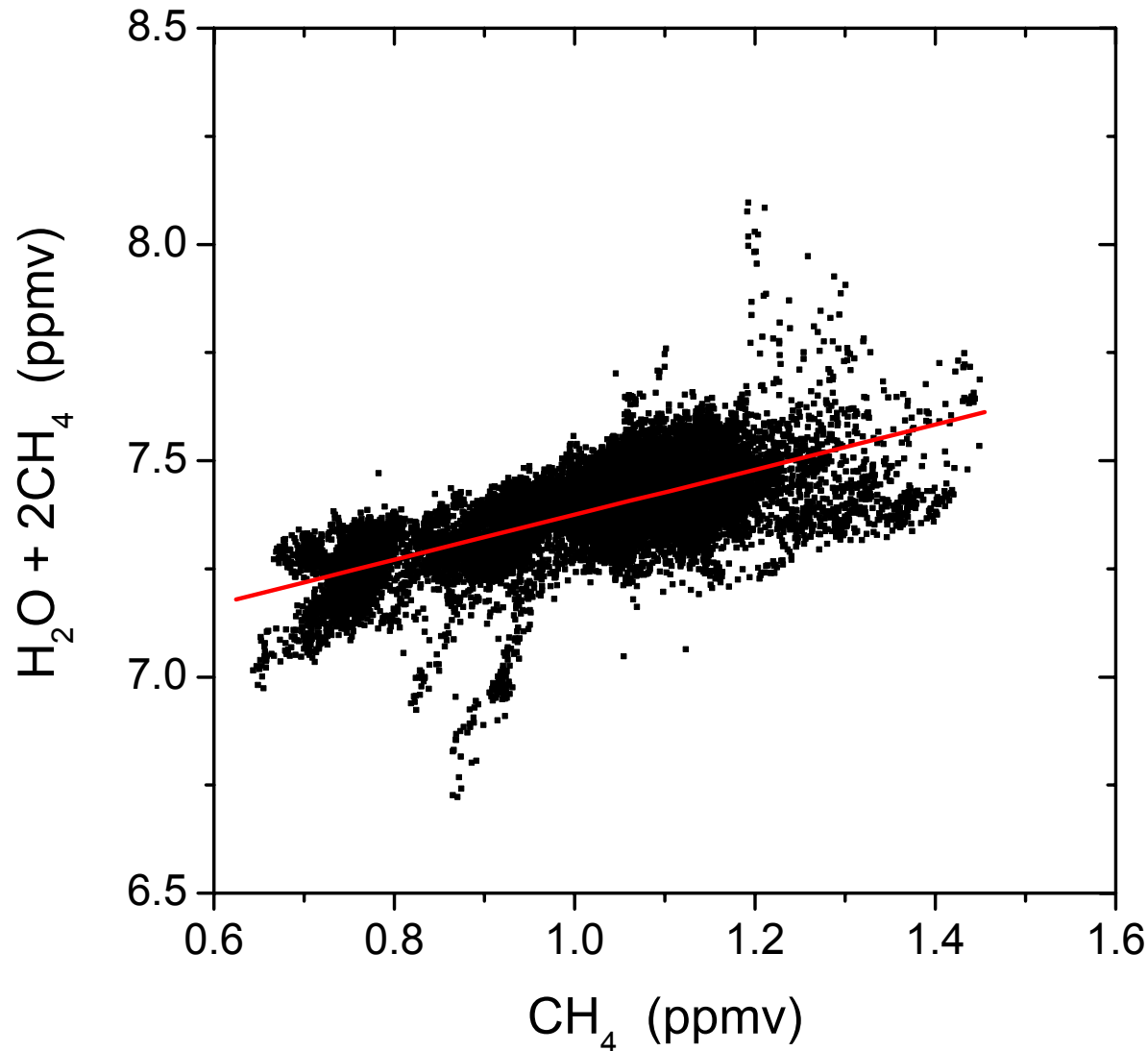


- Measurement location
- Other trajectories in cluster
- Location of cold pool
- Ice Frost Point
- Central trajectory
- NAT Condensation Point

Trajectory Calculations

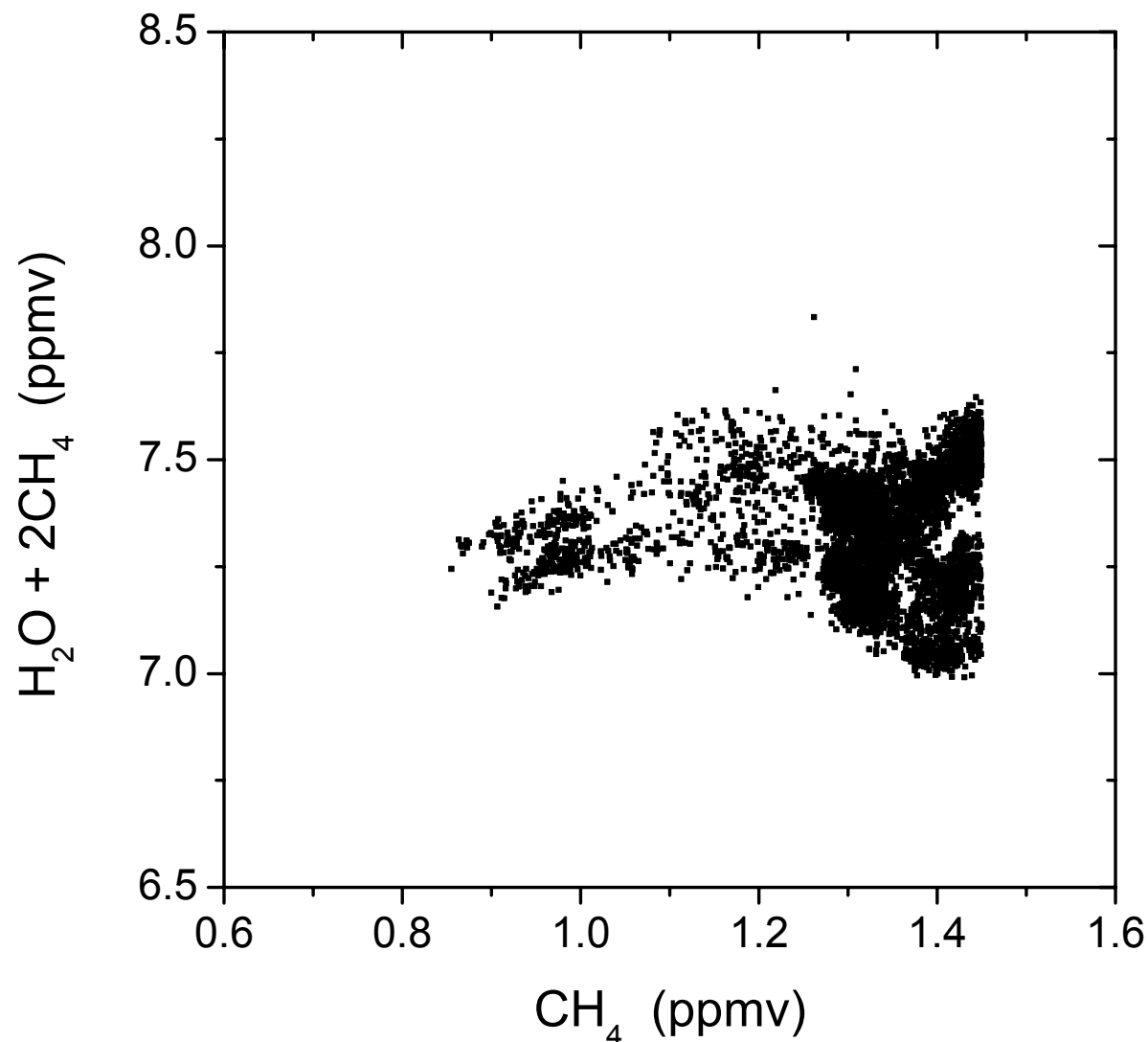
As shown above, a cluster of three-week diabatic back-trajectories from the dehydrated air parcel (48400 sec UT on Jan. 27, 2000) passed through the cold pool of the Arctic vortex in early Jan., experiencing temperatures as low as 183 K. For several days, the temperature was below the ice frost point, allowing freezing and growth of ice PSCs. Sedimentation of these particles irreversibly depleted the air parcel of water vapor.

$\text{H}_2\text{O} + 2\text{CH}_4$ in the Arctic Vortex



In the Arctic vortex, the sum $\text{H}_2\text{O} + 2\text{CH}_4$ decreases at lower CH_4 mixing ratios (higher altitude). JLH H_2O and ALIAS CH_4 are shown here, but the trend is also seen with data from the Harvard Lyman- α Hygrometer.

$\text{H}_2\text{O} + 2\text{CH}_4$ in the Extravortex and Vortex Edge Region



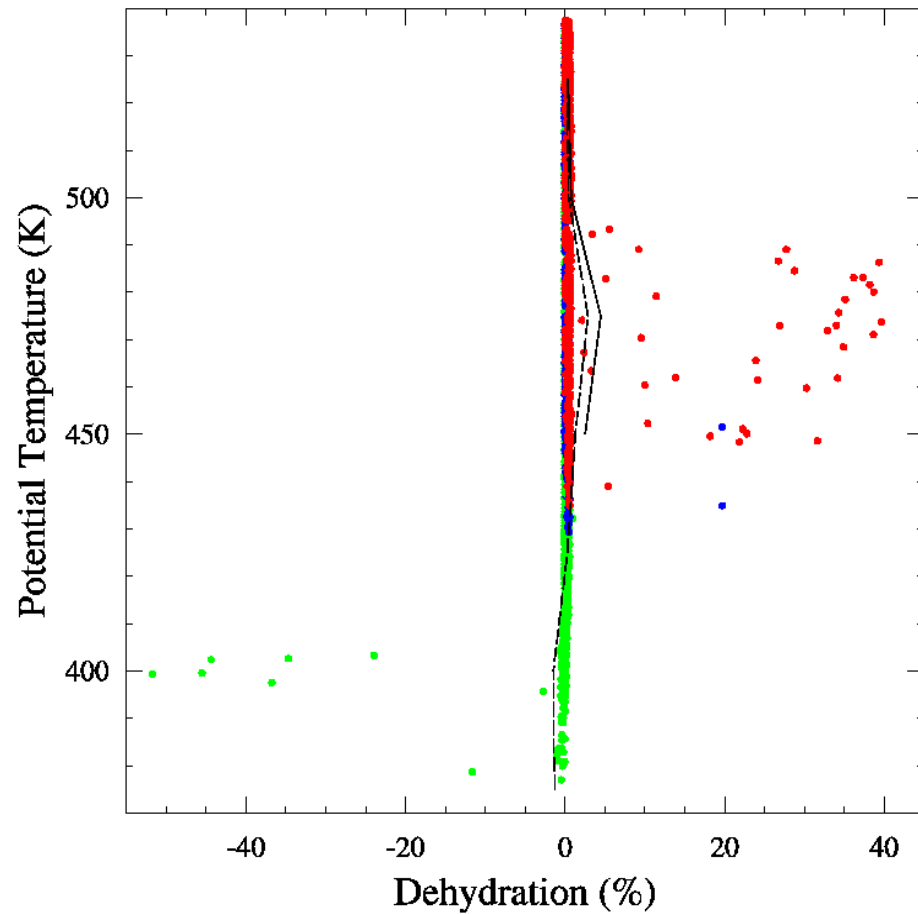
Outside the Arctic vortex, in the extravortex and vortex edge regions, the sum $\text{H}_2\text{O} + 2\text{CH}_4$ does not change as systematically as it does inside the vortex. JLH H_2O and ALIAS CH_4 are shown here, but the trend is also seen with data from the Harvard Lyman- α Hygrometer.

Modeling

To further explore the presence of ice PSCs in the winter Arctic polar vortex, we utilized the Integrated Microphysics and Aerosol Chemistry on Trajectories model (IMPACT) [Drdla, 1996]. This model follows diabatic trajectories of more than 2000 air parcels within the 1999-2000 Arctic polar vortex using UKMO temperatures [Schoeberl et al., 1993; Schoeberl et al., 2000]. A full particle microphysics code allows condensation, freezing, sublimation, and sedimentation of PSCs [Drdla et al., 2001].

Results for HetFrzB, $f=0.02\%$ Scenario

Dehydration on February 1st



- Average of points inside vortex (maximum = 4.5)
- - - Average of all points (maximum = 2.87, minimum = -1.45)
- Points outside vortex
- Points in vortex edge region
- Points inside vortex

The figure to the left shows model dehydration (%) of each individual diabatic trajectory, plotted against the value of the trajectory's potential temperature on February 1, 2000. The “HetFrzB” scenario of the IMPACT model assumes that NAT PSCs form by heterogeneous freezing every time an air parcel cools. Shown is the case where 0.02% of particles are assumed to contain heterogeneous nuclei.

Conclusions

- During the 1999-2000 winter, mean total hydrogen in the Arctic lower stratospheric vortex was not significantly different from the mean value outside the vortex. This implies negligible net loss of water from the Arctic stratosphere (400 – 470 K).
- Isolated episodes of dehydration and hydration were intercepted by the ER-2 aircraft on several flights. In particular, on the flight of Jan. 27, 2000, vortex air was dehydrated by as much as 0.63 ppmv.
- Diabatic back-trajectory calculations suggest this air parcel passed through the cold pool and experienced a dehydration event during Jan. 9 - 12, 2000.
- Total hydrogen decreased significantly with height throughout the lower stratospheric vortex, indicating a weak but widespread redistribution of water: water is low at altitudes corresponding to $\text{CH}_4 < 1.0$ ppmv ($\theta > 445$ on Feb. 1, 2000), and water is high at lower altitudes. A downward flux of water within the Arctic stratospheric vortex due to sedimentation and evaporation of PSCs is thus inferred.

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